INVESTIGATING THE BRANCHING OF CHINESE CLASSIFIER PHRASES: EVIDENCE FROM SPEECH PERCEPTION AND PRODUCTION

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ABSTRACT

The formal structure of the construction formed by a numeral (Num), a sortal classifier (C) or mensural classifier (M), and a noun (N), is controversial, as both left-branching [[Num C/M] N] and right-branching [Num [C/M N]] structures have been argued for in the literature. In this paper we report two psycholinguistic experiments on speech production and perception in Mandarin to investigate this branching issue. First, we applied the syntax-phonology interface of tone 3 (T3) sandhi and performed a phonological analysis of native speakers' tone sandhi patterns of [Num C/M N] phrases composed of T3 monosyllabic words. Second, we conducted a click-detection experiment to see how native speakers would perceive a click inserted in a C/M phrase composed of monosyllabic words, as compared to when it is inserted in other syntactic structures with attested left or right-branching. Results from both experiments supported the left-branching structure of classifier phrases.

KEYWORDS
Classifier phrase   **L**eft-branching   **R**ight-branching   **S**peech production **S**peech perception

1. INTRODUCTION

Mandarin Chinese is a typical numeral classifier language, where a numeral classifier, either a sortal classifier (C) or mensural classifier (M)[1], is essential when a noun (N) is quantified by a numeral (Num). While sortal classifiers and mensural classifiers form a single grammatical category of numeral classifiers, abbreviated as C/M, sortal classifiers categorize nouns by picking out an inherent property associated with that class of nouns, whereas mensural classifiers denote the quantity or amount of the noun (e.g., Her and Hsieh 2010). For instance, the sortal classifier *tiao* in (1a-b) highlights the long shape of the noun, while the mensural classifiers in (2a-b) solely denote the amount of the nouns.[2]

(1) Examples of sortal classifiers in Mandarin Chinese

a.	一	条	鱼	b.	一	条	虫
	yi	*tiao*	*yu*		*yi*	*tiao*	*chong*
	one	C_{long}	fish		One	C_{long}	worm
	'a fish'				'a worm'		

(2) Examples of mensural classifiers in Mandarin Chinese

a.	三	箱	书	b.	三	瓶	水
	san	*xiang*	*shu*		*san*	*ping*	*shui*
	three	M_{box}	book		three	M_{bottle}	water
	'three boxes of books'				'three bottles of water'		

This paper deals with the controversy over the constituency of the classifier construction [Num C/M N] in Chinese, i.e., do Num and C/M form a constituent [Num C/M] first or C/M and N merge first to form a constituent [C/M N]? Various syntactic arguments have been put forth in this debate by both sides. In this paper, we approach this issue from a psycholinguistic perspective and provide novel insights from two experiments involving speech production and perception.

With regard to speech production, we investigated the production of tone 3 sandhi in Mandarin C/M phrases. Tone 3 sandhi refers to a change of tone 3 (T3) to tone 2 (T2) before another T3, i.e., T3 T3 ⇨ T2 T3, as in *lao3shu3* ⇨ *lao2shu3* 'mouse' and *hao3 jiu3* ⇨ *hao2 jiu3* 'good wine'. This sandhi phenomenon applies consistently within disyllabic domains in which prosodic domains match syntactic domains (further details in Section 3). As an example, in the 1+2 right-branching structure of *lao3 shui3tong3* (old water-bucket) 'old water bucket', the T3 sandhi applies first within the disyllabic domain of *shui3tong3* and results in *shui2tong3*. The T3 sandhi thus does not apply to *lao3* because the following T3 of *shui3* has already changed to T2 *shui2*. The final tone pattern is thus T3 T2 T3 *lao3 shui2tong3*. However, the T2 T2 T3 pattern is expected for a 2+1 left-branching structure,

e.g., *zhan3lan3 guan3* ⇨ *zhan2lan2 guan3* 'exhibition hall'. Accordingly, a classifier construction [Num C/M N] involving three monosyllabic elements with T3, e.g., *wu3 ba3 san3* (five C$_{handle}$ umbrella) 'five umbrellas', should also have a prosodic pattern matching the syntactic branching as well. Specifically, if speakers interpret the structure as 1+2 and thus the right-branching [Num [C/M N]] structure, their production is expected to be the T3 T2 T3 pattern, while the T2 T2 T3 pattern is expected if the 2+1 left-branching [[Num C/M] N] is understood as the underlying structure.

With regard to speech perception, we conducted an experiment within the click-detection paradigm. Such experiments assume that a click inserted in the middle of a word tends to be perceived at the nearest syntactic boundaries by listeners, e.g., in the 1+2 right-branching structure *bu4 xiao3xin1* (not careful) 'not careful', a click inserted in the middle of the syllable *xiao3* tends to be perceived between *bu4* and *xiao3*. One can thus insert a click in the middle of a classifier phrase [Num C/M N] and record where listeners perceive the click to be located. If the click tends to be perceived between C/M and N, it infers a 2+1 left-branching structure, and if the click is mostly perceived between Num and C/M, it supports a 1+2 right-branching structure.

The two experiments reported were designed to assess the performance of native speakers of Taiwan Mandarin. As a disclaimer, we are aware that these two experiments do not represent absolute proof of the syntactic branching of Mandarin classifier constructions. Yet, we believe that these two experiments do provide novel evidence to the branching of the syntactic structure of the classifier phrase.

The paper is organized as follows. Section 2 presents a brief overview of the three different positions taken by various researchers in the debate over the syntactic structure of the classifier phrase. Sections 3 and 4 present the methodology and results of the two psycholinguistic experiments on speech production and perception, respectively, while the conclusion is drawn in section 5.

2. THE THREE APPROACHES

Three main approaches are found with regard to the constituency of the C/M phrase in Chinese. The more traditional approach is consistently left-branching, shown schematically in (3a), while the more recent formalist approach is right-branching, as in (3b). Yet, a split approach also exists, where both structures are claimed to be necessary.[3]

(3) Different syntactic structures proposed for [Num C/M N]
a.   Left-branching   b. Right-branching

```
              NP                              NumP
            /    \                          /      \
          QP      N                      Num        CLP
         /  \   shu1 (book)          san1 (three)  /   \
      Num    C/M                                 C/M     N
   san1 (three) ben3/xiang1 (C/M-box)    ben3/xiang1 (C/M-box) shu1 (book)
```
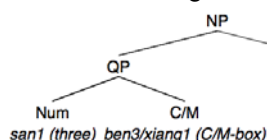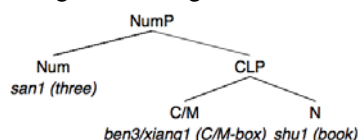
The dominant view in recent formalist syntax is right-branching, i.e., [Num [C/M N]] (Cheng and Sybesma 1999; Borer 2005; Tang 2005; Watanabe 2006; Huang, Li, and Li 2009; Li 2014; Hsu 2015). Under this approach, the number phrase (NumP) is generally analyzed as an independent projection taking the classifier phrase (CLP) as complement, which in turn takes the noun phrase (NP) as complement. Another account claims instead that C/M is the head of a UnitP, which takes NumP as specifier and NP as complement (e.g., Hsu 2015).

However, the C/M phrase is generally assigned a left-branching constituency (i.e., [[Num C/M] N]) by a significant number of earlier researchers (Li and Thompson 1981:105; Paris 1981:105-117; Huang 1982; Tang 1990; Croft 1994:151; Lin 1997:419; Hsieh 2008; Her 2012a, 2012b). A recent account adopts a functional perspective derived from mathematics where C and M are unified as one syntactic category under the concept of multiplicand (Her 2012a). The function of [Num C] is interpreted as [n × 1], where C encodes the numerical value of 1, while also highlighting an inherent feature of N; the function of [Num M] is similarly multiplicative, but the value of M is neither necessarily 1, nor necessarily numerical. Take 条 as an example of C and 打 *da3* 'dozen' as an example of M: 三条鱼 *san1 tiao2 yu2* (three C_{long} fish) = 3×1 fish = 3 fish, while 三打鱼 *san1 da3 yu2* (three M_{dozen} fish) = 3×12 fish = 36 fish. Consequent to Num and C/M forming a multiplicative unit, they must also form a syntactic constituent uninterrupted by N. As shown in (4), indeed no languages of the world are attested to show the [C/M N Num] or [Num N C/M] patterns.[4]

(4) Attested classifier word orders (Greenberg 1990[1972]:185)
a. [[Num C/M] N]   e.g., Mandarin
b. [N [NumC/M]]   e.g., Thai
c. [[C/M Num] N]   e.g., Garo (Tibeto-Burman)
d. [N [C/M Num]]   e.g., Jingpho (Tibeto-Burman)
e. *[C/M N Num]   (no languages)
f. *[Num N C/M]   (no languages)

Finally, some syntactic accounts adopt a split approach and contend that both left- and right-branching structures are required. For example, based on the various behaviors of the different types of classifiers, Zhang (2011)

argues that container measures, standard measures, partitive classifiers, and collective classifiers have a left-branching structure, whereas individual and individuating classifiers require a right-branching structure. There are strong arguments against this view, e.g., the complementary distribution between sortal classifiers and mensural classifiers indicate that they compete for the same syntactic position (Her 2012b:38, Hsu 2015:2). Moreover, several syntactic tests such as the *de*-insertion do show that the two types of classifiers behave in a similar way (Hsieh 2008; Her 2012a). However, additional explanations of these challenges have also been provided and the theoretical debate is still ongoing. For instance, it is claimed that the test of *de*-insertion is not a valid argument since the various structures that are allowed for [Num C/M (de) N] behave differently (Li 2014). The [Num C/M] structures that function as modifiers (relative clauses) are left-branching, whereas the other readings for entity and quantity are right-branching. Under this view, the function of [Num C/M] determines the grammatical structure, rather than the type of classifiers, e.g., the acceptance of *de* in the quantity-reading construction is a result of phonological insertion. The presence of *de* thus cannot be a criterion for determining syntactic structures since the different types of *de* need to be recognized first.

In summary, three different approaches to the constituency of the classifier phrase [Num C/M N] in Chinese are found: left-branching, right-branching, and split. It is important to note that this classification of the different accounts is based on the surface syntactic structure proposed and thus disregards the underlying structure postulated in movement-based accounts. While previous studies apply qualitative theoretical syntactic analyses, our study provides novel insight to the ongoing debate by undertaking two quantitative empirical studies of speech production and perception.

3. EVIDENCE FROM SPEECH PRODUCTION

The first experiment is an investigation of the syntax-phonology interface via the examination of Chinese tone 3 (T3) sandhi and its interaction with syntactic branching directions. Lin (2007:197) explains the T3 sandhi as follows: T3 changes to tone 2 (T2) before another T3. As demonstrated in (5), a T3 before another T3 undergoes T3 reduction and becomes a LL tone and this LL tone then changes to MH (T2) before another T3, which can be either a phrase final T3 (LH) or a non-phrase final T3 (LL). The difference between the two variants is not relevant to our analysis; we thus view them both as T3. It is also necessary to note that the derived T2 is attested in some studies to have a slightly lower overall fundamental frequency than a regular T2 in the same context (Zee 1980; Peng 2000; Chen and Yuan 2007). However native speakers do not detect this minor difference (Wang and Li 1967; Peng 2000). We thus follow Lin (2007) and assume that the changed T3 is T2. Following this logic, *lao3shu3* 'mouse' in (5b)

becomes *lao2shu3* since the two T3s in the original form are adjacent. Moreover, adding another T3 before *lao2shu3* such as *lao3 lao2shu3* 'old mouse' does not trigger T3 sandhi on this additional T3 since the following syllable is now T2, no longer T3.

(5) Tone 3 sandhi: T3 T3 ⇨ T2 T3 (Lin 2007 :197)
a. Rule: LL ⟶ MH/ __ LH or LL (i.e. T3⟶T2/__ T3)
b. Example 1:   *láoshǔ* 'mouse'

               T3 REDUCTION   TONE 3 SANDHI

[lɑu]**214** [ʂu]214 ⟶ [lɑu]**21** [ʂu]214 ⟶ [lɑu]**35** [ʂu]214

σ   σ   σ   σ   σ   σ

L H L H   ⟶   **L L** L H   ⟶   **M H** L H
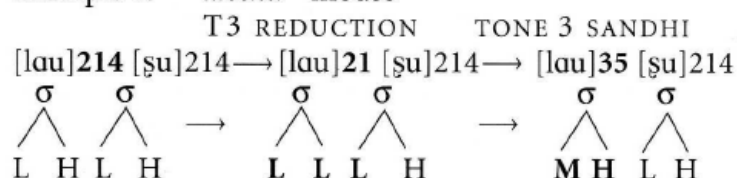
The rule itself seems rather straightforward; however, its applications can be complicated. As demonstrated in (6), the same sequence of T3s produces different results. This shows that other factors such as prosody and syntax also influence the sandhi process.

(6) Different T3 sandhi processes with the same tone ordering (Lin 2007:198)
a.   T3 T3 T3 T3 ⇨ T3 T2 T2 T3

米老鼠好	*mi*	*lao*	*shu*	*hao*
'Mickey Mouse is good'	Mickey Mouse			good
Base tone	3	3	3	3
Tone after sandhi	3	2	2	3

b.   T3 T3 T3 T3 ⇨ T2 T3 T2 T3

狗咬老鼠	*gou*	*yao*	*lao*	*shu*
'the dog bit the mouse'	dog	bite	mouse	
Base tone	3	3	3	3
Tone after sandhi	2	3	2	3

Regarding the prosodic behavior of T3 sandhi at the phrasal level, as attested by Lin (2007:208), the process of building the T3 sandhi domain should apply within a word and then to the smallest domain of the phrase and finally to the whole phrase. For example, in (7a-c), the most basic domain for T3 sandhi is a lexical item. Thus, for *lao3 hu3* 'tiger', the T3 of *hu3* triggers the tone sandhi of the preceding T3 in *lao3*, which changes to T2 as *lao2*. Tone sandhi may then involve the immediate constituent (Hsiao 1991:53-55): the smallest domain of a c-command relation can create matches of the most

basic metrical domain and form the Immediate Constituent Foot (ICF), which reflects the degree of the naturalness of the foot structure and renders a local match between the syntactic domain and the metrical domain. In (7b), the entire compound word *gou3 bing3 gan1* 'dog cookie' forms such a domain. Thus, the T3 of *bing3* triggers the tone sandhi of the preceding T3 in *gou3*, resulting in *gou2 bing3 gan1*. Finally, the connecting of the ICFs together at the phrasal level may also trigger T3 sandhi. As shown in (7c), *zhan3 lan3* 'exhibition' first forms a domain in which the T3 of *lan3* triggers the tone sandhi of the preceding T3 in *zhan3*, resulting in *zhan2 lan3* 'exhibition'. Then, when expanding the domain to the entire compound word *zhan2 lan3 guan3* 'exhibition hall', a similar process occurs between the remaining two T3s, resulting in *zhan2 lan2 guan3*. Finally, with the noun phrase merging with *li3* 'inside', T3 sandhi applies again between *guan3* and *li3*, leading to the final result: *zhan2 lan2 guan2 li3* 'inside the exhibition hall'.

(7) Example of T3 sandhi domains
a. Within a lexical item

老虎	*lao*	*hu*	
'tiger'	tiger		
Syntax	[	]NP	
Base tone	3	3	
ICF	2	3	
Phrasal	2	3	

b. Within an immediate constituent foot (ICF)

狗饼干	*gou*	*bing*	*gan*	
'dog cookie'	dog	cookie		
Syntax	[[	]	]NP	
Base tone	3	3	1	
ICF	2	3	1	
Phrasal	2	3	1	

c. Within the phrasal level

展览馆里	*zhan*	*lan*	*guan*	*li*	
'inside an exhibition hall'	exhibition		hall	inside	
Syntax	[[[	]	]NP	]	
Base tone	3	3	3	3	
ICF	2	2	3	3	
Phrasal	2	2	2	3	

Following the demonstration above, we further observe that T3 sandhi in Mandarin is sensitive to syntactic branching, as shown in (8) with examples adapted from Duanmu (2005:5). In the left-branching structure (8a),

mai3 hao3 'finished buying' forms an immediate constituent foot first, due to their relation of a verb and an aspect marker. T3 sandhi may therefore occur within the disyllabic domain and *mai3 hao3* changes to *mai2 hao3*. After this first level, the domain is enlarged to include *jiu3* 'wine', which triggers T3 sandhi on the preceding *hao3*, the perfective aspect marker. The result obtained is thus *mai2 hao2 jiu3* 'finished buying wine'. On the other hand, in the right-branching structure (8b), *hao3 jiu3* 'good wine' forms an immediate constituent foot first, due to their relation of an adjective and a noun. T3 sandhi thus occurs within the disyllabic domain and *hao3 jiu3* changes to *hao2 jiu3*. The domain is then expanded, and the difference with (8a) is that T3 sandhi cannot be applied to *mai3* here, since the preceding T3 has already changed to T2.

(8) Left and right-branching syntactic structure affecting T3 sandhi
a. Left-branching

买好酒	*mai*	*hao*	*jiu*
'finished buying wine'	buy	PERF	wine
Syntax	[[	]	]
Base tone	3	3	3
ICF	2	3	
Phrasal	2	2	3

b. Right-branching

买好酒	*mai*	*hao*	*jiu*
'to buy good wine'	buy	good	wine
Syntax	[	[	]]
Base tone	3	3	3
ICF		2	3
Phrasal	3	2	3

It is proposed in some studies, e.g., Shen 1994, that a T3 before a T3 that has already changed into T2 can still change into T2 optionally; however, since we follow Lin (2007)'s definition that the T2 derived from T3 and the original T2 are the same, we will not include this divergence in our discussion. It is also necessary to highlight that previous studies, e.g., Hsiao 1991, attest that the speed of speech may also affect the prosodic domain and cause disruption in the syntax-phonology mapping; therefore, we assume the

speed to be at the normal rate of casual speech, not at a particularly fast or slow rate, to avoid unnecessary complications in the analysis.

It is important to point out that this syntax-phonology matching is disrupted when the domain is larger than two syllables. As demonstrated by Chen and Yuan (2007), the T3 sandhi rule matches with syntactic boundaries within a disyllabic prosodic domain, but turns to optional within a trisyllabic or larger environment. As an example, *mi3 lao2 shu3* 'Mickey Mouse' in (9a) is one NP domain; however, the tone sandhi first occurs between the rightmost two syllables *lao3* and *shu3*, which block the T3 sandhi for the first syllable *mi3*, since the following syllable has already changed from T3 to T2. In (9b), taken from Duanmu (2005:13), T3 sandhi occurs first between the ICF *lao2 hu3* 'tiger'; however, with the boundaries expanded T3 sandhi becomes optional, resulting in three possible readings. In the first, T3 sandhi applies cyclically within the domain, while in the second the ICF *lao3 hu3* *'tiger'* undergoes T3 sandhi**,** while the two other words *xiao3* 'small' and *zhi3* 'paper' form a domain of their own, triggering T3 sandhi and resulting in *xiao2 zhi3*. For the third option, T3 sandhi applies within the medium domain of *zhi3 lao3 hu3*, but is blocked at the boundary of *xiao3* 'small', obtaining *xiao3 zhi2 lao2 hu3*.

(9) T3 sandhi in domains larger than disyllabic
a. Within a trisyllabic domain

米老鼠	*mi*	*lao*	*shu*	
'Mickey Mouse'	Mickey	Mouse		
Syntax	[	[	]]NP	
Base tone	3	3	3	
ICF		2	3	
Phrasal	3	2	3	

b. Within a four syllable domain

小纸老虎	*xiao*	*zhi*	*lao*	*hu*	
'small paper tiger'	small	paper	tiger		
Syntax	[	[	[	]]] NP	
Base tone	3	3	3	3	
ICF			2	3	
Phrasal	2	2	2	3	
	2	3	2	3	
	3	2	2	3	

Even though there is no consensus on what constitutes the obligatory sandhi domain limits within phrases (Duanmu 2005), it is well-accepted that tone sandhi within a disyllabic lexical item and the smallest disyllabic domain in the phrase is obligatory (Shih 1986; Chen 2000; Duanmu 2000; Feng 2004; Wang 2004), as shown in (10) from Duanmu (2005:14) within a

word (10a), a compound (10b), and a phrase (10c). Therefore, our experiment only selects monosyllabic Num, C/M, and N, so that they form disyllabic domains when constituting the ICF and the syntax-phonology matching is still obtained between the different constituents.

(10) Tone 3 sandhi applying within a disyllabic domain
a. Word

蚂蚁	*ma*	*yi*	
'ant'	ant		
Syntax	[	]	
Base tone	3	3	
ICF	2	3	
Phrasal	2	3	

b. Compound

米酒	*mi*	*jiu*	
'rice-wine'	rice	wine	
Syntax	[	]	
Base tone	3	3	
ICF	2	3	
Phrasal	2	3	

c.   Phrase

你好	*ni*	*hao*	
'How are you?'	you	good	
Syntax	[[ ]	]	
Base tone	3	3	
ICF	3	3	
Phrasal	2	3	

Some previous studies used T3 sandhi to support the right-branching hypothesis; however, they included non-disyllabic materials such as 五百檔 影片 *wu3bai3 dang3 ying3pian4* 'five-hundred C movie', in which Num and N are already disyllabic and the prosodic preference toward disyllabic foot parsing may disrupt the direct match with the syntax (Hsu 2015:8). Our study only selects monosyllabic Num, C, and N so that the first formed disyllabic domain matches in terms of the syntax and prosody (more explanation is provided in the following section).

3.1 Rationale of the Speech Production Experiment
If Num and C/M are immediate constituents of the same domain, and therefore left-branching, we expect tone sandhi to occur obligatorily between their monosyllabic versions, since their combination would obtain a

disyllabic domain suitable for T3 sandhi. On the other hand, tone sandhi between C/M and N may also occur, but since it crosses a domain boundary, it is expected to be optional (Hsiao 1991). An example with sortal classifiers is demonstrated in (11) with *wu3 ba3 san3* 'five C$_{handle}$ umbrella'. In (11a), the structure is left-branching; therefore, the numeral and the classifier form an ICF first, triggering the change of *wu3* to *wu2*. In the second stage where the noun *san3* is incorporated, tone sandhi changes the preceding *ba3* to *ba2*. If right-branching in (11b) is correct, then C/M and N form an ICF first, the T3 of *san3* triggers the tone sandhi of the preceding T3 of *ba3*, resulting in *ba2 san3*. Tone sandhi can no longer occur with *wu3* 'five' since the preceding T3 has already changed toT2.

(11) T3 sandhi with sortal classifiers in the syntax-phonology interface
a. Left-branching

五把伞	*wu*	*ba*	*san*
'five umbrellas'	five	C$_{handle}$	umbrella
Syntax	[[		]	]
Base tone	3	3	3
ICF	2	3	
Phrasal	2	2	3

b. Right-branching

五把伞	*wu*	*ba*	*san*
'five umbrellas'	five	C$_{handle}$	umbrella
Syntax	[	[		]]
Base tone	3	3	3
ICF		2	3
Phrasal	3	2	3

The same process applies for mensural classifiers, as an example in (12) with *wu3 da3 bi3* 'five M$_{dozen}$ pen' shows. In (12a), the structure is left-branching; therefore, the numeral and the mensural classifier form an ICF first, then tone sandhi applies, changing *wu3 da3* to *wu2 da3*. At the phrasal level, the following noun *bi3* 'pen' is included in the domain and triggers tone sandhi of the preceding *ba3* 'M-dozen', displaying the result of *wu2 da2 bi3*. On the other hand, if the structure is right-branching as in (12b), C/M and N form an ICF first then tone sandhi is applied, changing *da3 bi3* to

da2 bi3. At the phrasal level, the numeral *wu3* is involved but tone sandhi cannot be triggered since the original T3 of the following C/M has already been modified to T2 in the ICF prosodic level.

(12) T3 sandhi with mensural classifiers in the syntax-phonology interface
a. Left-branching

	wu	*da*	*bi*
五打笔			
'five dozen pens'	five	M_{dozen} pen	
Syntax	[[	]	]
Base tone	3	3	3
ICF	2	3	
Phrasal	2	2	3

b. Right-branching

	wu	*da*	*bi*
五打笔			
'five dozen pens'	five	M_{dozen} pen	
Syntax	[	[	]]
Base tone	3	3	3
ICF		2	3
Phrasal	3	2	3

Following this logic, various combinations of the [Num C/M N] structure with T3 are possible, and each branching direction makes different predictions regarding T3 sandhi outcomes. Therefore, we designed an experiment to first verify that left and right-branching indeed affect the tone sandhi process. If the results of the experiment are positive, we can then apply the same methodology to the classifier structure to check whether speakers produce sandhi supporting the left-branching or right-branching hypothesis. As in our speech perception test, this experiment gathers three conditions dependent on the syntactic types of a trisyllabic phrase in each sentence. The first condition is the [XYZ] phrases of [Num C/M N]. The other two conditions are control conditions: one contains attested left-branching [XY+Z] phrases, while the other involves attested right-branching [X+YZ] phrases; both types include materials at the morphological and phrasal levels. Again, all three elements of XYZ are monosyllabic and of T3, to ensure that the length of the XYZ constituent

does not cause interference in the phonological process and that T3 sandhi on the first and second syllable is triggered. For each condition, there are twelve materials, six morphological materials and six phrasal materials. Materials from both levels are required to verify that the phonological process is not affected by the word boundary, i.e., that it also applies to structures with monosyllabic Num, C/M, and N.

Starting with the [XY+Z] conditions, a set of morphological materials is first shown in (13). As an example, 展览馆 *zhan3lan3guan3* 'exhibition hall' is a trisyllabic word.[5] Internally, 展 *zhan3* and 览 *lan3* first form a constituent meaning 'exhibition', which is then combined with 馆 *guan3* 'hall'. This process thus results in a [XY+Z] morphological structure.

(13) Morphological materials in the [XY+Z] condition for the speech production experiment

展览	馆		演讲	稿
zhan3lan3	*guan3*		*yan3 jiang3*	*gao3*
exhibition	hall		speech	text
'exhibition hall'			'text of a speech'	

保守	党		总统	府
bao3shou3	*dang3*		*zong3tong3*	*fu3*
conservative	party		president	mansion
'conservative party'			'presidential palace'	

冷水	澡		选举	法
leng3shui3	*zao3*		*xuan3ju3*	*fa3*
cold water	bath		election	law
'cold shower'			'electoral laws'	

The [XY+Z] structure may also be phrasal, where XY is a constituent that forms a larger phrasal constituent with Z. For example, with 影响小 *ying3xiang3xiao3* in (14), 影 *ying3* and 响 *xiang3* form a noun meaning 'effect', which is combined with the predicative adjective 小 *xiao3* 'small'.

(14) Phrasal materials in the [XY+Z] condition for the speech production experiment

手法	巧		米酒	好
shou3fa3	*qiao3*		*mi3jiu3*	*hao3*
method	skillful		sake	good
'the method is skillful'			'the sake is good'	

保险	倒	影响	小
bao3xian3	*dao3*	*ying3xiang3*	*xiao3*
insurance	fail	effect	small
'the insurance failed'		'the effect is small'	

野狗	少	水平	稳
ye3gou3	*shao3*	*shui3zhun3*	*wen3*
wild dog	few	level	stable
'there are few wild dogs'		'the level is stable'	

The same method applies for the second control condition [X+YZ], which also includes six morphological materials and six phrasal materials. The full list is displayed in (15), taking 老古板 *lao3gu3ban3* 'old-fashioned' as an example: even though the three syllables form a single word, in their internal structure 古 *gu3* and 板 *ban3* combine first, then 老 *lao3* is added to result in the idiomatic meaning of 'old fashioned'. To avoid confusion between morphological and phrasal materials, all of the morphological materials of both the [XY+Z] and [X+YZ] conditions were cross-checked in the Academia Sinica Corpus annotations and by frequency of occurrence. Only materials with the highest occurrence are selected for inclusion in our study to avoid any non-standard reading of materials that may affect the judgment of the participants.

(15) Morphological materials in the [X+YZ] condition for the speech production experiment

米	老鼠	纸	老虎
mi3	*lao3shu3*	*zhi3*	*lao3hu3*
rice	mouse	paper	tiger
'Mickey mouse'		'paper tiger'	

老	古板	小	俩口
lao3	*gu3ban3*	*xiao3*	*liang3kou3*
old	old-fashioned	young	couple
'old-fashioned person (pejorative)'		'a young couple'	

总	整理	冷	处理
zong3	*zheng3li3*	*leng3*	*chu3li3*
general	summary	coldly	handle
'general summary'		'handle it with a low-key style'	

As for the phrasal materials for the [X+YZ] condition, the full list is shown in (16). Similar to the first control condition, they include combinations of two distinct parts of speech, e.g., in 选 里 长

xuan3li3zhang3, 里 *li3* and 长 *zhang3* form first the noun 里长 *li2zhang3* 'ward chief', which is then attached to the verb 选 *xuan3* 'choose'. It may be noted that the phrasal materials of the two control conditions include various combinations of verbs and nouns or nouns and adjectives without a fully balanced ratio; nevertheless, since the syntactic categories of the constituents are not attested to have an influence in the disyllabic prosodic domain, we do not control for these factors specifically.

(16) Phrasal materials in the [X+YZ] condition for the speech production experiment

选	里长	把	美女
xuan3	*li3zhang3*	*ba3*	*mei3nu3*
choose	mayor of the district	flirt	beautiful girl
'to elect the mayor of the district'		'to flirt with a beautiful girl'	

跑	诊所	有	理想
pao3	*zhen3suo3*	*you3*	*li3xiang3*
run	clinic	have	ideal
'to go (often) to the clinic'		'to have an ideal'	

砍	主管	给	喜帖
kan3	*zhu3guan3*	*gei3*	*xi3tie3*
cut	manager	give	wedding invitation
'to fire a manager'		'to give a wedding invitation'	

The expected results with our control conditions are that different branching directions result in a different tone sandhi. Both types start with underlying tones [3 3 3], but in the structure [XY+Z], whether at the morphological or phrasal level, the T3 of Y will trigger tone sandhi on X, followed by the T3 of Z, which provides tone sandhi for Y, resulting in [2 2 3]. On the other hand, the structure [X+YZ] should result in the tones [3 2 3], since Z will first trigger tone sandhi on Y and consecutively block the tone sandhi on X. If this turns out to be correct, the tone sandhi observed with the [XYZ] structure should reflect the syntactic branching of the constituent and the tone sandhi pattern of [Num C/M N] would be an indicator of its syntactic structure. If the tone sandhi pattern of [Num C/M N] is [2 2 3], it will be aligned with the left-branching structure and vice-versa for [3 2 3][6]. Therefore, we gather six materials for sortal classifiers and six materials for mensural classifiers. All three elements in [Num C/M N] are monosyllabic with an underlying T3, as in the two control conditions. The same quantity of materials is gathered for the control and testing conditions to ensure that the data is balanced and for it to be subject to statistical analysis. The full list of our tested classifiers is displayed in (17). In total only three numerals are

applicable to our experiment since only three monosyllabic numerals bear T3 in Mandarin Chinese; they are respectively 两 *liang3* 'two', 五 *wu3* 'five', and 九 *jiu3* 'nine'. The classifiers and nouns are also selected by their frequency of occurrence in the Academia Sinica Corpus.

(17) Sortal classifiers in the testing material for the speech production experiment

两	把	锁	两	尾	狗
liang3	*ba3*	*suo3*	*liang3*	*wei3*	*gou3*
two	C_{handle}	lock	two	C_{tail}	dog
'two locks'			'two dogs'		

五	口	井	五	本	谱
wu3	*kou3*	*jing3*	*wu3*	*ben3*	*pu3*
five	C_{mouth}	well	five	C_{volume}	partition
'five wells'			'five partitions'		

九	首	曲	九	朵	槿
jiu3	*shou3*	*qu3*	*jiu3*	*duo3*	*jin3*
nine	$C_{heading}$	music	nine	C_{flower}	Portia
'nine pieces of music'			'nine Portia flowers'		

The same methodology applies for mensural classifiers, as shown in (18). It is important to point out that we applied the definition of Her (2012a:1688) to differentiate between sortal and mensural classifiers, as explained in our literature review.

(18) Mensural classifiers in the testing material for the speech production experiment

两	场	雨	两	打	表
liang3	*chang3*	*yu3*	*liang3*	*da3*	*biao3*
two	M_{event}	rain	two	M_{dozen}	watch
'two rainfalls'			'two dozen watches'		

五	斗	米	五	捆	草
wu3	*dou3*	*mi3*	*wu3*	*kun3*	*cao3*
five	M_{dipper}	rice	five	M_{bundle}	grass
'five dippers of rice'			'five bundles of grass'		

九	碗	水	九	种	鸟
jiu3	*wan3*	*shui3*	*jiu3*	*zhong3*	*niao3*
nine	M_{bowl}	water	nine	M_{kind}	Bird
'nine bowls of water'			'nine kinds of birds'		

While a qualitative phonological analysis based on the previous content could by itself give this issue a convincing explanation, the intuition of native speakers may vary according to geographical regions and be biased if solely based on the intuition of one author. Our study thus provides a quantitative analysis based on experiments with native speakers to partially overcome this limitation. The detailed methodology is explained in the following section.

3.2 Methods of the Speech Production Experiment

Twenty individuals were recruited from National Chengchi University. They were native Mandarin speakers without self-reported speech disorders or professional vocal training. Participants gave written consent before the experiment and received NT$ 120 as a fee for their participation. The stimuli consisted of 36 [XYZ] phrases evenly distributed amongst the three conditions: [Num C/M N], [XY+Z], and [X+YZ] phrases. The [Num C/M N] condition was made up evenly by sortal classifiers and mensural classifiers, as displayed in (17) and (18). For the latter two conditions, each contained six morphological materials and six phrasal materials (13-16). The participants' responses were recorded for the entirety of the speech production task.

With regard to the procedure, the participants completed nine practice trials and asked questions if necessary. In each trial, the participants saw a fixation in the middle of the screen for 250 milliseconds (ms). Then, the three characters appeared in the middle of the screen for 250 ms, which should be long enough for the participants to read the characters: according to the findings of Tsai (2000), when Mandarin native speakers read a paragraph, the average reading speed for 2.5-3.3 characters is 220-230 milliseconds (ms), and the focus of the eye includes the first character on the left and three characters on the right of the visual hint point. The distance between the screen and [the] participants' eyes was 70 ± 10 centimeters. The font size of the words was 18. Finally, the third slide was blank for 1000 ms for participants to say the stimuli. The procedure of a trial is displayed in Figure 1: the first slide shows the visual hint point, followed by the testing material, and the procedure is completed with the empty space lasting for the duration of 1000ms.
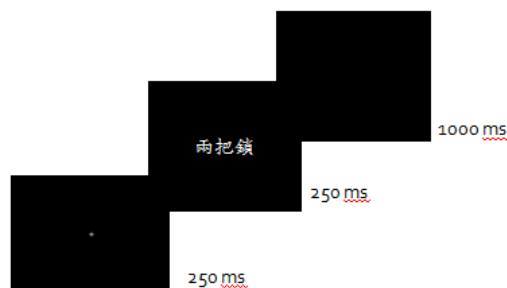
Figure 1. The procedure of a trial in the speech production experiment

The obtained data were analyzed via two checking processes. First, two linguistic experts (PhD level) annotated the tones on the constituents based on their listening judgment. Second, Praat 6.0.23 (Institute of Phonetic Sciences - University of Amsterdam, Amsterdam, The Netherlands) was used to analyze the recordings. Afterwards, the responses were statistically evaluated in one-way repeated measures ANOVA. IBM SPSS 21.0 was used for the statistical analysis (IBM Corp., Armonk, NY, USA) with the α value set at .05.

3.3 Results and Discussion of the Speech Production Experiment

The result of the first round of ratings based on listening by experts is shown in Figure 2, in which both raters reached an inter-rater reliability of 99.5%, i.e., the two experts gave the same ratings for 99.5% of the trials. Our focus lies on the tone change of the first syllable: if it is tone 2, it supports the left-branching structure; if it is tone 3, it favors right-branching. The ratio of the y-axis is based on the percentage of observed tone 2s in the first syllable. In the [XY+Z] condition, the ratio of tone 2 is 94.4% (34/36 trials), meaning that, on average, 94.4% of the trials with the structures of [XY+Z] conditions were produced in the [2 2 3] pattern by each participant. This fact supports the prerequisite that syntactic branching does affect phonology. On the other hand, the right-branching structure [X+YZ] only received 0.8% of annotations as [2 2 3], meaning that the majority of the trials were produced as [3 2 3]. In summary both control conditions demonstrated that syntactic branching affects the phonological process: if the structure is left-branching [XY+Z], the tone sandhi result is [2 2 3], while it is [3 2 3] if the structure is right-branching [X+YZ].
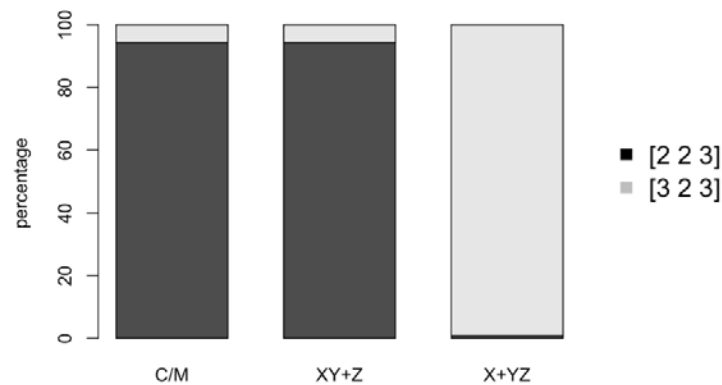
Figure 2. Result of the speech production test based on human rating

Based on the results derived from the control conditions, the tone sandhi pattern of [Num C/M N] should equally be relevant to its syntactic structure: if the tone pattern is [2 2 3], it is left-branching, while [3 2 3] relates to right-branching. As observed in Figure 2, 94.4% of the [Num C/M N] materials were annotated as [2 2 3]. The percentage of the tone 2 changes of the first syllable in the C/M, [XY+Z], and [X+YZ] structures was significantly different in the one-way analysis of variance (ANOVA) test ($F_{(2, 18)}$ = 1215.364, p < .001), with its divergence from the [X+YZ] structure also being highly significant (p < .001). This relation is also observed in the Praat rating results, as shown in Figure 3: 81.4% (29/36 trials) of the [XY+Z] structures were annotated as [2 2 3], while only 6.1% of the [X+YZ] structures were recorded as such, demonstrating that syntactic branching still had an effect on the tone 3 sandhi results. Furthermore, 79.2% of the C/M trials were annotated as [2 2 3], and the percentage of the tone 2 changes of the first syllable in the C/M, [XY+Z], and [X+YZ] structures was also significantly different in the one-way ANOVA test ($F_{(2, 18)}$ = 116.037, p < .001).
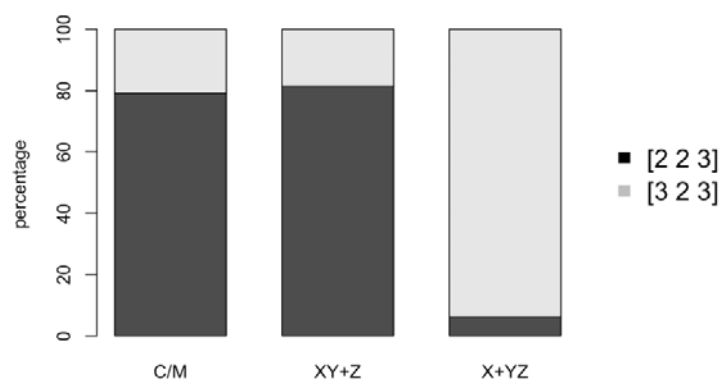
Figure 3. Result of the speech production test based on Praat rating

As a summary, in this experiment via the syntax-phonology interface, participants mostly produced C/M structures with a T3 sandhi of [2 2 3], which is consistent with the left-branching structure. Similar experiments may be designed to suit other classifier languages with tone sandhis, and a pilot study on Shanghainese provided similar results supporting the left-branching structure. However, it is necessary to note that not all tone sandhi effects from other languages interact with syntax in similar ways. For example, if tone sandhi applies cyclically, then it is not possible to determine the branching direction. A detailed analysis of the language prosodic system is needed before using it as positive or negative evidence.

4. EVIDENCE FROM SPEECH PERCEPTION

Our second experiment based on speech perception relies on the use of the classical method where participants are asked to locate an inserted click in a sentential material. The gestalt theory predicts that the stronger the boundary, the greater its effect in attracting the perception of the click; for example, clicks in the middle of 'Anna' are attracted towards the major syntactic boundary in these two sentences: 'In her hope of marrying, Anna was surely impractical' and 'Your hope of marrying Anna was surely impractical' (Garrett, Bever, and Fodor 1966). In the first sentence, the major syntactic boundary is between 'marrying' and 'Anna'; thus, the click tends to be perceived there. In the second sentence, the major syntactic boundary is between 'Anna' and 'was'; therefore, the click is commonly perceived in that location instead. This finding shows that syntactic structure affects speech perception. We apply the same paradigm to investigate the syntactic structure of classifier phrases. We are aware that the click experiment has been criticized for various reasons, such as being an off-line experiment and that its result may be influenced by other factors such as intonation (Levelt

1978:10; Cohen and Mehler 1996). Nevertheless, the fact that clicks tend to be perceived at syntactic boundaries is not controversial. We thus consider that the click paradigm is appropriate for our purpose.

4.1 Rationale of the Speech Perception Experiment

In this experiment, we select stimuli from the Mandarin Hearing in Noise Test (MHINT), where the volume and reception threshold for sentences are properly controlled. Each sentence is composed of ten words. Three conditions based on trisyllabic phrases are designed: the first condition is the [XYZ] phrases of [Num C/M N]. The other two conditions are control conditions: one contains left-branching [XY+Z] phrases, while the other involves right-branching [X+YZ] phrases. The clicks appear exactly in the middle of Y in all conditions. Due to the limitation of space, we do not display a full list here, but an example is shown in (19).

(19) Example of the control conditions in the speech perception test

a. [XY+Z]   b. [X+YZ]

讲话   时   不   小心
jiang3hua4   *shi2*   *bu4*   *xiao3xin1*
talk   when   not   careful
'when talking'   'not careful'

All three elements in [XYZ] are monosyllabic to ensure that the click is perceived as separating the total structure into left or right-branching, i.e., the result can either be [XY+Z] or [X+YZ]. In (19a), X *jiang3* and Y *hua4* first form the verb 'to talk', which is then combined with *shi2* 'when', resulting in a left-branching structure. In (19b), Y *xiao3* and Z *xin1* concatenate first as 'careful', then X *bu4* is attached as a negation. As for the [Num C/M N] structures, they are also formed by monosyllabic elements, e.g., 九只猫 *jiu3zhi1mao1* 'nine C_{animal} cat' meaning 'nine cats'. In the test materials, these [XYZ] constituents are part of a full sentence, as demonstrated in (20). As an example of the control material [XY+Z], in (20a) 讲话时 *jiang3hua4shi2* is in the middle of the sentence. The click appears right in the middle of 话 *hua4*. However, the [XYZ] constituents might appear in different positions in the sentences as we can only choose from the limited available stimuli that suit our experimental needs. Notably, we control the distribution of the click in the sentence among the three conditions. That is, the chance that the click appears in the first/middle/last third of the sentence is similar amongst the three conditions. Afterwards, the participant is asked in which position he/she perceives the click; the available options include every slot between each character, i.e., starting from left to right: between 他 *ta1* and 刚 *gang1*, between 刚 *gang1* 才 *cai2*, among others.

The same method applies for the control material [X+YZ] as displayed in (20b).

(20) Examples of the control materials in the speech perception test
a. [XY+Z] condition

他	刚才	**讲话**	**时**	吞吞吐吐
ta1	*gang1cai2*	*jiang3hu4*	*shi2*	*tun1tun1tu3tu3*
he	just	talk	when	mumble

'he was mumbling when talking a moment ago'

b. [X+YZ] condition

他	切	菜	**不**	**小心**	切伤	手指
ta1	*qie1*	*cai4*	*bu4*	*xiao3xin1*	*qie1shang1*	*shou2zhi3*
he	cut	vegetable	not	careful	cut wounded	finger

'he accidentally cut his finger when cutting vegetables'

We expect that the participants will perceive the click to be located at the nearest syntactic boundary. For [XY+Z] materials, they should detect the click between XY and Z, while the click will be perceived between X and YZ for [X+YZ] conditions. As in the earlier speech production test, we also gathered materials at the morphological and phrasal levels. If the two control conditions prove that syntactic boundaries do influence perception of the click, we can then apply the same methodology to the classifier phrases and deduce where the syntactic boundary is located according to the perception of participants.

For this purpose, sentences with [Num C/M N] phrases are selected, the location of [Num C/M N] within sentences being similar to our two control conditions. Furthermore, the [Num C/M N] phrases are also composed of monosyllabic constituents to resemble the [XYZ] materials. As shown in (21) with 一口井 *yi4kou2jin3* (one C_{mouth} well) 'one well', the click is inserted in the middle of 口 *kou3*, the classifier. If the click is perceived after the classifier, it suggests that the main syntactic boundary is separating the noun, with Num and C/M under the same branch, thus left-branching. If the click is perceived before C/M, the right-branching structure is supported.

(21) Example of the [Num C/M N] materials in the speech perception test

这里	有	一	口	井	从不	结冰
zhe4li3	*you3*	*yi4*	*kou3*	*jing3*	*cong2bu4*	*jie2bing1*
here	have	one	C_{mouth}	well	never	freeze

'There is a well here, which never freezes.'

Note that this speech perception experiment does not involve T3 sandhi, but the chosen materials for Num, C/M, and N are again all monosyllabic to avoid interference from word length.

4.2 Methods of the Speech Perception Experiment

Twenty Mandarin native speakers were recruited from National Chengchi University. They gave written consent before the experiment and each received NT$ 120 as a fee for their participation after the completion of the required tasks. Stimuli were chosen from the MHINT and consisted of 36 [XYZ] phrases. There were three conditions in this study: [Num C/M N], [XY+Z], and [X+YZ] phrases. Each condition included twelve different phrases.

In the procedure, the participants first completed ten practice trials and asked questions if necessary before the experiment started. In each trial, the participants saw a fixation in the middle of the screen for 250 milliseconds (ms). Then, participants heard the sentence before the sentence and the numbers indicating the corresponding response button appeared on the screen. The participants had up to five seconds to select where they perceived the click. The inter-trial interval was 250 ms. Figure 4 displays an example of this procedure: After the visual hint point, participants heard the testing material and were provided five seconds on the following slide to decide where they perceived the click. An empty slide then appeared before the beginning of the next trial.
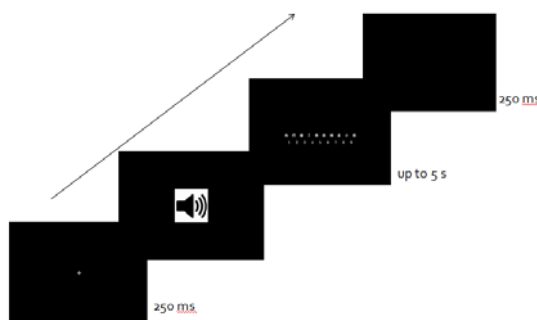

Figure 4. The procedure of a trial in the speech perception experiment

The results were analyzed in one-way repeated measures ANOVA via IBM SPSS 21.0 (IBM Corp., Armonk, NY, USA) with the α value set at .05.

4.3 Results and Discussion of the Speech Perception Experiment

The data first shows that in an average of 72.1% of the cases (dashed line in Figure 5), participants perceived the click either before or after the character in which it was inserted, e.g., in the structure 一口井 *yi4kou2jing3* (one C_{mouth} well) 'a well', where the click was inserted in the classifier 口

kou3, the participants perceived the click either before (between 一 *yi4* and 口 *kou3*) or after (between 口 *kou3* and 井 *jin3*) the classifier. If the click was perceived in other positions, it was annotated as 'incorrect'. The detailed ratio for each participant in Figure 5 shows that the general performance of the participants for all testing materials (including [XY+Z], [X+YZ] and [Num C/M N]) was stable enough to permit further analysis.
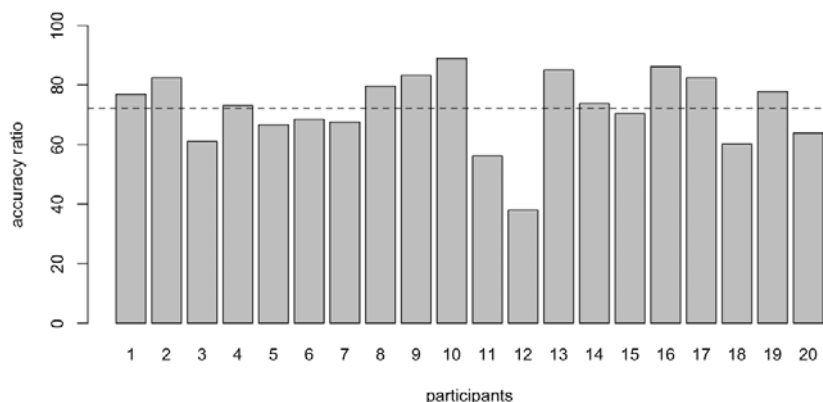

Figure 5. Participants' average performance in the speech perception test

Then, we checked the perception rate for each condition: [XY+Z], [X+YZ], and [Num C/M N], as displayed in Figure 6. The Y axis represents the ratio of perceiving the click either before or after the character into which the click was inserted. The gray color indicates that the participants annotated the click before the middle character (Y or C/M, depending on the condition), while the black color marks that the participants noted the click after the middle character. We expected that the click would have the tendency to be perceived after Y (in black) in the case of the [XY+Z] conditions, while the click should be perceived before Y (in gray) in the case of [X+YZ]. This is indeed what is observed in the results: for [XY+Z], 52.7% of the trials were interpreted as 'click after Y', while for [X+YZ], 41.1% of the trials were interpreted as 'click before Y'. As for the C/M phrases, in 46.5% of the cases, the click was interpreted after Y, producing results similar to those found in the left-branching [XY+Z] control condition.
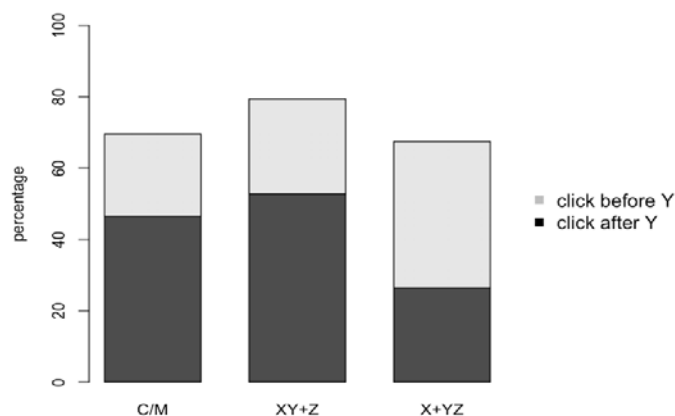
Figure 6. Responses to the three conditions in the speech perception test

We also conducted statistical analyses. We first divided the number of 'perceiving the click after' by the number of trials for each of the three conditions, as displayed in Figure 7. For instance, the participants tended to perceive the click after Y (0.65) for the [XY+Z] control condition, while they were much less likely to perceive it after Y (0.38) with the [X+YZ] condition. These differences support the hypothesis that the click has the tendency to be perceived on the nearest syntactic boundary. Furthermore, in the case of the structure of [Num C/M N], the participants tended to perceive the click after Y (0.66), which is a similar result to that for the [XY+Z] condition, supporting the hypothesis that [Num C/M N] is left-branching with [Num C/M] as a constituent. A statistical test of one-way ANOVA also provided evidence supporting our observation as the results turned out to be statistically significant (significant main effect of conditions, $F_{(2, 38)} = 29.563$, $p < .001***$).
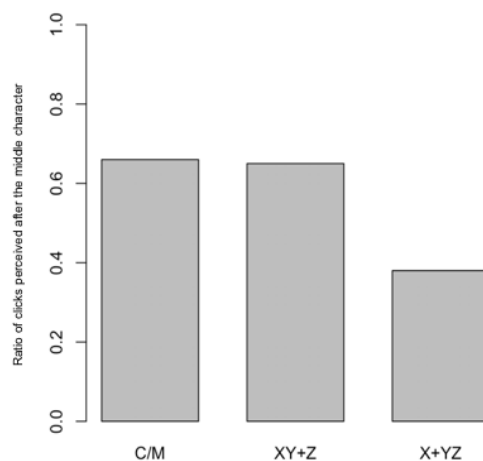
Figure 7. Ratio of clicks perceived after the middle character

Finally, we note an interesting observation, that a small but noticeable number of [X+YZ] trials were perceived as having the click after Y. While the difference between the two control conditions is statistically significant, this observation shows that though the click experiment is statistically valid, its output is less stable than that of the speech production. We thus recommend a combined use of the two tests in further studies to assess the effect of the syntax-phonology interface on tone sandhi.

5. CONCLUSION

In this study, we have provided novel insights into the surface syntactic structure of classifier phrases in Chinese, based on two psycholinguistic experiments investigating the T3 sandhi phenomena and the click paradigm in speech production and perception. In the construction [Num C/M N], where C is a sortal classifier and M is a mensural classifier that occurs between a numeral and a noun, the results from both experiments provide support for the surface left-branching hypothesis at a statistically significant level. While additional theoretical discussions may be developed based on the underlying structure proposed in a movement-based syntactic theory, we also suggest that our experiments should be replicated in different tone languages with classifiers, e.g., Shanghainese, to further investigate their consistency at a cross-linguistic level.

NOTES

1.   Alternative names do exist for both subcategories in the literature, e.g., classifiers versus measure words and classifiers versus massifiers.

2.   It is important to point out that the mensural classifiers in a classifier language like Chinese are syntactically different from nouns that serve as terms of measure in a non-classifier language like English, e.g., *three boxes of books* and *three bottles of water*. For more details, see Her (2012a:1682).

3.   Note that in the recent literature on this debate, the two terms 'left-branching' and 'right-branching' are commonly used rather loosely in referring to the two options of the constituency in the classifier construction [Num C/M N], i.e., [[Num C/M] N] and [Num [C/M N]], respectively, regardless to as to which element is considered the head in either [Num C/M] or [C/M N]. Thus, though Hsieh (2008) considers Num the head in the [Num C/M] constituent, all the recent works on this debate accept her account as left-branching, including Hsieh herself**,** in fact.

4.   Two apparent exceptions are found in the literature (Watters 1981; Adams 1989), but have since been disputed (Kihm 2005; Her 2017a, 2017b).

5.   To avoid confusion, we display the underlying tones here, which are all T3; the constituent is thus a viable candidate for T3 sandhi. The tone pattern in actual speech should be *zhan2lan2guan3*.

6.   In phrases such as 买把伞 *mai3 ba3 san3* 'buy C$_{handle}$ umbrella', the output of tone sandhi pattern may be [2 2 3] and similar to left-branching**,** while the syntactic structure is actually right-branching. This is due to an optional application within the cyclic domain: left-branching structures can only result in [2 2 3], while right-branching generates [3 2 3] and optionally [2 2 3]. This is not a counter-example since for a left-branching structure the reading of [3 2 3] is not acceptable to speakers (Duanmu 2005:21-23).

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